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CANADIAN SCIENTISTS REPORT

INTRODUCTION

WITH this issue of the JOURNAL, a series of articles in astronomy and related sciences is inaugurated. The articles have been planned to present authoritative and yet non-technical reviews and accounts of scientific work in which Canadians are taking a part. The project was first discussed about one year ago at a large meeting of the Council of our Society, in Toronto, and has been endorsed by all concerned. The Editors take much pleasure in seeing the plans come to fulfilment, and wish to record their gratitude for the kind co-operation of the professional astronomers and other Canadian scientists in making the series possible.

It is the hope that this series of articles will be interesting to the members of the Society and, at the same time, instructive. The rapid and continuing expansion of scientific research in Canada is one of the most important facets of our national development. It is the privilege and duty of our Society to help all the members to an appreciation of this scientific growth through the pages of the JOURNAL. In addition, these articles enable our scientists to explain and interpret their work and that of their colleagues to a large circle of sympathetic and informed fellow citizens. Of the value of the articles the Editors are not in doubt; their earnest hope is that the series will be prolonged until the whole scope of our science, and many of its fringes, are adequately represented.

R. M. PETRIE, *President.*

I. THE GROWTH OF ASTRONOMY IN CANADA

By R. M. Petrie

Astronomy in Canada has, like the country itself, exhibited a rapid growth and reached its present stature almost within the compass of a single lifetime. We can trace the development of Canadian Astronomy almost to its birth, because this took place not very long ago and the records survive. This account was prepared to give the readers of the Journal a general, overall, impression of the growth of our science. No attempt has been made to give a complete story nor to include all places, dates, and names. More factual and historical records are available in past volumes of the Journal and in other publications.* The writer begs the reader's indulgence for the omission of many interesting details; he rests his hopes of escaping the just wrath of the many whose names are not mentioned in the reflection that the chief architects of Canadian Astronomy are among the most modest of scientists.

The earliest astronomical activity I shall record happened in 1839. In that year the Astronomer Royal, upon the representations of the Admiralty, sent some instruments to Canada. Along with magnetic and meteorological instruments there were included a refracting telescope and a mural circle. The latter were not mounted at first, however, and the establishment of the first astronomical observatory in Canada appears to have taken place at Fredericton† in 1851, and in 1854 an observatory was founded in Quebec City. In that same year a group of citizens in Kingston acquired a telescope and some other instruments and installed them in the public park. The meteorological station at McGill University was set up in 1862; in 1879 this became an astronomical observatory through the addition of a refracting telescope, a transit-instrument and other equipment. Before the end of the 19th century a number of educational institutions acquired astronomical instruments, and telescopes were owned, and used, by a considerable number of private persons. A good deal of enthusiastic searching of the sky seems to have taken place during these early days but there does not appear to have been any long-term programme apart from time-service supplied by one or two institutions. As an interesting example of a co-operative study during this

*See, for example, *A History of Science in Canada*, edited by H. M. Tory, The Ryerson Press, Toronto, 1939, and *Astronomy in the University of Toronto*, C. A. Chant, University of Toronto Press, 1954.

†An account of this historical event is given by Professor J. E. Kennedy in this Journal, see vol. 48, p. 220, 1954; or vol. 49, p. 151, 1955.

period, one can mention telescopic observations of the 1882 transit of Venus by groups of amateur astronomers at Woodstock, Quebec, Fredericton, Kingston, Montreal, Whitby, and Toronto.

It is interesting that the first stirrings of astronomical science antedated Confederation by more than a quarter of a century. Today's splendid flowering of Canadian Astronomy had its roots in a community engaged in settling and developing a vast and primitive land. Great credit is due to those enlightened citizens who, for more than fifty years, stimulated public interest in the heavens and pursued astronomy as an avocation in a pioneering country.

Astronomy assumed a more permanent and continuing form near the end of the 19th century. This was brought about in the first instance by the extensive surveys required in the opening of western Canada to settlement and the uniting of the Dominion by railway. Far-flung surveying operations needed a base observatory where the adjustment of instruments could be made, and for the accurate measurement of time and star-position. Such an observatory was provided in Ottawa, about the year 1890, in the form of a modest wooden structure erected on Government property. Thus the Government of Canada took its first step in developing astronomical science. It was a significant step for, since that day, our Government has been a guiding hand in providing facilities and encouraging advances. This strong support has given Canadian Astronomy a rather distinctive character. It has stimulated a more active interest among the people as a whole and it has been an important factor in making it possible to plan and to acquire the powerful telescopes and elaborate instrumentation needed for modern observational work. At the same time this policy has created opportunities for many Canadians who would otherwise have been forced to follow their interests beyond our borders.

The first Government observatory in Ottawa was recognized as a temporary expedient pending a more substantial installation. The Chief Inspector of Surveys, W. F. King, and his associates were men of vision. They urged upon the authorities the desirability of providing a permanent observatory for the pursuit of astronomical research as well as for the necessary practical services. The advice was accepted and thus the Dominion Observatory, in Ottawa, came into being in 1904. The main telescope was an equatorially mounted refractor of fifteen inches aperture—a very handsome instrument in those days! The Observatory acquired a meridian circle, a transit-instrument, and a solar telescope as well as the necessary auxiliary equipment. Later on telescopes for direct photography and stellar photometry were added.

The Dominion Observatory was, from its inception, more than an astronomical institution. The study of geophysics was actively followed through investigations in seismology, terrestrial magnetism, and gravity. These subjects will not be discussed further here but it should be noted that the geophysical studies have continued to expand along with the astronomical work. They continue to make contributions to our knowledge of the earth and to the discovery and exploration of Canada's physical resources.

While astronomy was being established in Ottawa, important developments were taking place in Toronto. This City, the cradle of Canadian Astronomy, has maintained an active interest beginning with the Toronto Astronomical Club in 1868, which became The Astronomical and Physical Society of Toronto, then the Toronto Astronomical Society, and finally, in 1903, The Royal Astronomical Society of Canada. Before this, groups of amateurs affiliated with the Toronto nucleus had been established at Meaford, Simcoe, Brantford, Woodstock, and Galt. After incorporation as a new Society, Centres were formed at Ottawa (1906), Peterborough (1907), Hamilton (1908), and Winnipeg (1910), to name some of the earliest. These Centres were, in some cases, the successors to earlier organizations.

The influence exerted by the Toronto group was caused, in part, by its close connection with the University through the adherence of a number of members of the faculty. A most important connection was made in 1892 when C. A. Chant, then Lecturer on Physics, became a member. For more than fifty years Professor Chant has laboured unceasingly to promote the cause of astronomy. He it was who persuaded the University to establish a Department of Astronomy and he himself for twenty-five years gave professional training to many past and present Canadian astronomers.

Beginning about the turn of the century Professor Chant sought to cultivate general interest in astronomy by advancing the aims of the Society with lectures and articles directed to the public generally. He realized that a powerful telescope and a permanent observatory were essential if the needs of the Society and the University were to be satisfied and he kept these aims always in mind. After many disappointments his work came to fulfilment with the establishment of the David Dunlap Observatory in 1935.

The Society's connection with astronomical development in Canada would not be adequately described without some mention of the JOURNAL. This has been published continuously since 1907, when it succeeded the earlier organ, *The Transactions of the Astronomical and Physical Society*

of Toronto. The JOURNAL helps to unite amateur astronomers throughout Canada by printing reviews, reports of activities at various Centres, and articles of general interest, but its service goes beyond that. As a medium for the publication of research and technical papers it assists astronomers in communicating new work and in linking Canada, astronomically speaking, with the international community. Here, again, we are indebted to Professor Chant, who for nearly fifty years has acted as Editor and has given unsparingly of time and energy so that the JOURNAL might contribute to the growth of astronomy in Canada.

With the founding of the Dominion Observatory, astronomical work in Canada embarked upon a period of expansion. The Ottawa astronomers soon established a time service and contributed accurately measured star positions. Important observations of the sun were made. One of the outstanding astronomical achievements of the day was the successful application of spectroscopy to stellar measurements by J. S. Plaskett and his colleagues, using the fifteen-inch Ottawa refractor. The main applications were to the measurement of stellar line-of-sight speeds and the discovery and investigation of spectroscopic double stars. So rapid was the progress that it soon became evident that a much more powerful telescope was required if the work were to continue. Once again the Government, impressed with the international reputation of the Ottawa astronomers, took a forward step. The Dominion Astrophysical Observatory was built in 1918 near Victoria, B.C., with the (then) largest telescope in the world, and dedicated to investigation of the nature of stars and the sidereal system. The Royal Society of Canada, the Royal Astronomical Society of Canada, and many private individuals joined the professional astronomers in advising the Government—the new Observatory was thus a truly national institution. To Dr. Plaskett must go our grateful thanks for his unremitting zeal in keeping the project before the authorities and his contributions to the design of telescope and spectrograph.

The powerful new telescope on the Pacific coast with its versatile spectrograph began at once to produce important information. The Observatory soon became known for its contributions to our knowledge of stellar motions, double stars, the structure of the galaxy, and the physical and chemical nature of the stars. These matters will continue to absorb its activities for some time to come. In addition to the research work accomplished, the existence of a major astronomical institution in British Columbia has encouraged, generally, interest in astronomy in western Canada.

Following the transfer of most of the work in stellar spectroscopy to

Victoria, the Dominion Observatory expanded the time service and continued activity in positional astronomy and solar spectroscopy. Direct photography and photographic photometry of stars were undertaken. A substantial expansion has taken place in the last decade with work on the infra-red spectrum of the sun, instrumental advances in the positional work, and studies of the spectra of the high-temperature stars. A new interest has been added with the photography and analysis of meteor spectra, in which study Ottawa occupies a leading position.

It was mentioned earlier how the efforts of Professor Chant, in 1935, culminated in the splendid gift of the David Dunlap Observatory to the University of Toronto. Equipped with the largest telescope in Canada, modern spectrographs, and other auxiliary instruments, this Observatory has already made valuable additions to our knowledge of stellar motions, double stars, variable and peculiar stars, and star clusters. In addition to its research work, the David Dunlap Observatory is the chief centre of training for Canadian students of astronomy, and its influence upon the future of the science in Canada is thus very great.

During the last decade, it has become possible to study the sun, the stars, and the galaxy by means of receivers capable of detecting radiation of very long wave-lengths. This new and exciting method of exploration is called Radio Astronomy, and closely allied to it is the radar method of studying the reflection of artificially-generated radiation. Some valuable work has already been done in these directions in Canada. Radio studies of the sun, and its connection with upper atmospheric conditions, have been going forward in Ottawa at the National Research Council. Valuable studies of meteor swarms by radar methods have been carried out jointly by the Dominion Observatory and the National Research Council. As this is written, plans are being made at the David Dunlap Observatory to study the sun and the "radio stars," while galactic explorations by the new method are being contemplated at the Dominion Observatories.

It is not possible, in this brief sketch, to describe the origin and growth of more than the largest centres of Canada's astronomical work. Many universities, however, have student observatories at which undergraduate instruction is given and this important development is increasing. Of recent years, for example, we have seen the gifts of the Hume Cronyn Observatory to the University of Western Ontario (1940), and the Cyril G. Wates Telescope to the University of Alberta (1943). As this is written, steps are being taken to remount in a student observatory the telescopes at the University of Manitoba. Developments such as these gratify all who are interested in the welfare of astronomy. They guarantee

the facilities necessary to the training of astronomers of the next and succeeding generations.

While the foregoing account is largely the record of professional development, there is a parallel story to be told of the activities of the non-professionals. Space does not permit of its inclusion here, but one must at least record the phenomenal growth from the Toronto Astronomical Club with eight members at its first meeting to the Royal Astronomical Society of Canada in 1955 with more than 2,000 members. This remarkable increase has played its part in the growth of Canadian Astronomy by influencing public opinion in support of the professional astronomer. The expansion is still taking place in a most encouraging manner. As late as 1954 the Society welcomed into its membership a new Centre in Halifax, while in a recent issue of this JOURNAL we read of the construction of an observatory by amateur astronomers at Regina. Throughout our brief history, the professional and amateur astronomers have worked together and have prospered. Together they founded and nourished our astronomical science: together they will assure its progress in Canada and increase its service to astronomy everywhere.

Dominion Astrophysical Observatory,
Royal Oak, B.C.,
January 1956.

A STONE PILLAR ON THE TRUE MERIDIAN LINE

By J. E. Kennedy

In Fredericton, New Brunswick, on the campus of the University, stands a stone pillar, a stalwart memorial to the contributions of Dr. William Brydone Jack in the field of practical surveying. This landmark is situated on the true meridian line at a distance of 8.82 chains due South of the transit room of the Observatory. It has not been used in scientific observations for the past twenty-five years.

The interest of a member of the University Senate has prevented it from falling into complete obscurity. A record book of observations made at this stone pillar was uncovered about five years ago and presented to the Archives of the Library by Dr. C. McN. Steeves. Through his efforts, the pillar has since been protected by an enclosure, and a copy of Dr. Jack's report to the Surveyor General placed on display at the site.

In 1840, Dr. William Brydone Jack was appointed to King's College, Fredericton, as Professor of Mathematics, Natural Philosophy and Astronomy. It is logical to find that his interest in the practical aspects of these subjects should prompt him to introduce a course on surveying in the college curriculum. It is noteworthy that the introduction of such a practical subject should make a large contribution to the very survival of King's College.

The foresight of Dr. Jack in realizing the need for training students in engineering, together with the support he received from the Governor of New Brunswick, Sir Edmund Head, were responsible for King's being one of the first institutions in British North America to initiate, in 1854, a course in engineering instruction. In achieving this end, Dr. Jack had met with bitter opposition internally from the classically trained and highly cultured President, Dr. Jacob. But in the period, 1855–1860, the existence of this course of practical training for the young men of the Province enabled the College to withstand successfully the violent attacks made upon it by the members of the Legislative Assembly of New Brunswick.

Two decades later, when Dr. Jack was President of the University of New Brunswick, the records reveal that his interest in practical surveying had continued. The 14th Annual Report of the Crown Land Department of the Province of New Brunswick for the year ending October 31st, 1874, concluded with the following:

Board of Examiners

On the 27th July last, Dr. W. B. Jack, Edward Jack and W. Crockett, Esquires, with myself, were appointed the Board of Examiners for the examination of Candidates for admission to practice as Land Surveyors in this province. Mr. W. P. Flewelling, Jr., has since been appointed its Secretary, and a "True Meridian" Line has been established at the University on which the present variation of the Magnetic Compasses used by Land Surveyors can now be observed.

I have the honor to be,
Your Honor's most obedient servant,
Benj. R. Stevenson,
Surveyor General.

Crown Land Office,
Fredericton, Feb. 1st, 1875.

On April 8th, 1874, an Act had been passed (37° Victoriae, A.D. 1874, Cap. XXI) pertaining to Land Surveyors and the Survey of Land in the Province of New Brunswick. A few sections of this Act are quoted below.

(1) *Board of Examiners appointed:*

There shall be a Board of Examiners for the examination of candidates for admission to practice as Land Surveyors in the Province of New Brunswick, and such Board shall consist of the Surveyor General, and such other competent persons not exceeding three, as shall be appointed from time to time by the Lieutenant Governor in Council.

(4) *Qualifications of Candidates for Surveyor:*

Before any person is admitted to practice as Land Surveyor in this Province he shall be examined by the Board of Examiners as to his competency and the sufficiency of his instruments: The Board shall test him as to his knowledge of the following subjects—Arithmetic, Algebra, Geometry, Mensuration, Trigonometry and the use of Logarithms, Surveying and Dividing Lands, Plotting and Map Drawing, and Spherical Trigonometry and Astronomy so far as will enable him to lay down a true meridian line and ascertain the latitude; he shall also be required to submit his instruments for the approval of the Examiners, and perform such practical operations in their presence as they may require, both in regard to the use of the instruments and their adjustments; . . .

(8) *For Testing Instruments a true meridian line &c. to be laid down:*

For the purpose of testing and verifying Surveyors' Instruments there shall be laid down and properly marked, on suitable ground at Fredericton, the exact length of a standard chain, and the direction of the true meridian; . . .

(9) *Instruments now in use to be tested within one year:*

For the sake of ensuring greater uniformity in the instruments used, and the work done by different Surveyors, every Surveyor now practising in the Province shall, within one year from the passing of this Act, bring or send to Fredericton his instruments, for the purpose of having them tested and verified by the Board of Examiners; and the Board shall have power to condemn and forbid the use of all instruments which they may find defective or incapable of giving accurate results; . . .

The first meeting of the Board was held on January 11th, 1875. The Surveyor General was made Chairman and W. P. Flewelling was appointed Secretary. A report to the Surveyor General, dated October 17th, 1874, was then presented by Dr. Jack.

Sir:

I beg to report that I have attended to your instructions about the laying down of a True Meridian Line for the purpose of determining the variation of the Magnetic Needle, and for testing the accuracy of Surveyors' Compasses.

At a point in the Meridian of the University of New Brunswick and 8.82 chains due South from the Transit Room I had a stone pillar erected, and to prevent its being affected by the frost I had the ground around it thoroughly drained and a drain formed leading to some distance from it.

FIG. 1—After eighty-one years, the Stone Pillar stands today less than 5° off the vertical, as a monument to Dr. Jack's ability as a practical field engineer. The Pillar is a fine grain diorite rock, probably cut and fashioned in a stone quarry about three miles from the city of Fredericton.

Once Dr. Jack had taken observations for ensuring the accuracy of the position of the pillar, true bearings of six conspicuous objects were made with a theodolite, three on the east side and three on the west side of the

meridian line from which he determined the magnetic variation at Fredericton.

I. *On the East Side of the Meridian Line*

A. The upper part of the cross on the spire of the Roman Catholic Church.
B. The upper part of the cross on the spire of the Episcopal Cathedral.
C. The top of the spire of Mr. Gibson's Church on the Nashwaak.

II. *On the West Side of the Meridian Line*

D. The vertical finger of the hand on the top of the spire of the Methodist Church.
E. The Eastern edge (below the coping) of the most Easterly chimney of the University Building.
F. The Western edge (below the coping) of the most Westerly chimney of the University Building.

Of the four church spires mentioned, only *D* remains today as it was in 1874. This is the famous spire on the Wilmot United Church, sometimes called the "Church of the Index Finger". A large hand, with the index finger pointing upwards, terminates the top of the steeple.

In 1876, through the efforts of Dr. Jack an additional storey was added to the University Building and the chimneys were raised to a new elevation, but not changed in bearing with reference to the true meridian line. Over a period of years, trees gradually began to obscure the conspicuous objects from view, and in 1892, another point *G* was added, the top of the lightning conductor of the Parliament Building. The "new" Buff and Berger Theodolite, with which the bearing of this object was taken is still used by students in surveying at the University today.

A Committee consisting of Dr. Jack and Edward Jack was appointed by the Board at its first meeting, and instructed to lay down the exact length of a standard chain in the Hall of the University. By June 1875, this work had been completed and was reported on by Dr. Jack. A recent search of the most probable floor areas in the Arts Building has not revealed the location of this reference standard.

The Act defined, in Section (4), the qualifications required of candidates for Surveyor. The first meeting of the Board ended with an examination of presumably their first applicant. The candidate "was examined orally and by written questions (the questions proposed being of the simplest nature) but he failed to give satisfaction. Moreover, he professed no knowledge of Algebra, and also has no instruments. The Board therefore resolved that he could not receive a Commission".

An example of the neat records made and copied by Dr. Jack is shown below.

On March 10th, 1875, a certain Mr. Buttimer brought two identical circumferentors for testing. In the record book, Dr. Jack distinguished these instruments by referring to them as "Buttimer" and "McManus". The derivation of "McManus" is herewith suggested.

Dr. Jack was born and educated in Scotland and carried his native tongue to his adopted country. In his lectures in Mathematics the symbols

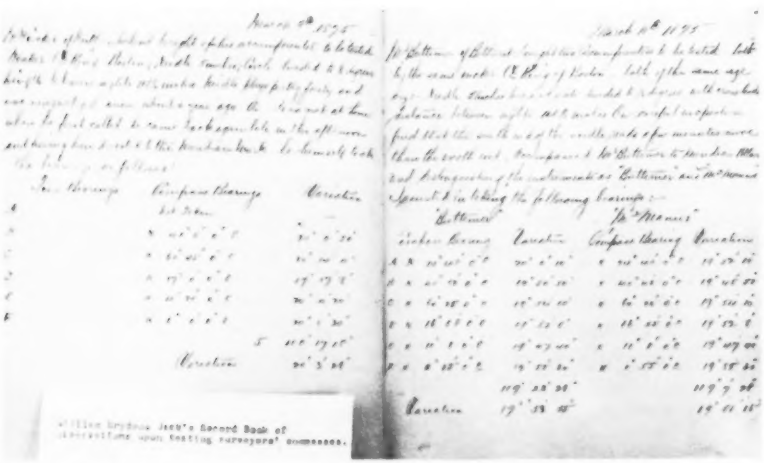

FIG. 2–Typical pages from one of the record books of measurements made by Dr. Jack in testing surveyors' compasses, circumferentors and chains.

of plus and minus were always pronounced as plus and manus. To the students, he became fondly known as "Manus Jack". His good humour and entertaining nature were at their best when the "McManus" instrument was being tested.

The implementing of Section (9) of the Act was the chief reason that so large a number of instruments (compasses, circumferentors and chains) were submitted for testing in the years 1875 and 1876. The record book contains some very shrewd comments on the ability of some of the Deputy Land Surveyors in handling their equipment, and on whether the instruments should be passed or rejected for service.

Astronomical work was to Dr. Jack a labour of love and the testing of surveyors' instruments was no more lucrative. A summary of his work completed between February 18th, 1875, and August 9th, 1876, was found in a memo attached to the Record Book of the Board of Examiners. A total of forty-two instruments were examined in this interval. On the out-

side of the memo is a warrant to issue Dr. Jack a sum of $25.00 to cover his efforts.

A plot of the magnetic data for Fredericton (Herbert, 1926) gives the value of the magnetic variation for the year 1870 as 19° 38′W., for 1880 as 19° 54′ W., with an annual change of 1.6′ W. In the period, 1874–76, the variation was from 19° 45′ W. to 19° 48′ W. In 1874 Dr. Jack reported 19° 15′ W., which is not in good agreement with the above, but in 1875, the average given by the tests of the various instruments was 19° 52.6′ W.

"The needle attached to the theodolite being short is not susceptible of great accuracy". Hence, this original discrepancy becomes quite understandable. In his initial report, and on a number of other occasions, Dr. Jack urged the Surveyor General to purchase a "superior instrument" to be used as a standard of reference in testing surveyors' compasses. There is no record that his suggestion materialized.

Magnetic observations for Canada, and the transfer of these data to magnetic maps, are now made by the staff of the Division of Geomagnetism of the Dominion Observatory, Ottawa, headed by Mr. R. G. Madill. Their records show that observations were taken at this stone pillar as recently as the years 1925, 1927 and 1929. There may well be "repeat" magnetic measurements made at this pillar in the years to come.

The twentieth century belongs to Canada. The increased industrial growth of this nation is forcing us to search for additional sources of minerals and raw materials. New areas must be surveyed and developed each year by trained engineers from this and other Canadian Universities. It is well to pause and recognize the debt we owe to pioneers like Dr. Jack in this field of practical surveying. Their foresight and action during the past century are making it possible for us to meet the present challenge.

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THE FORMATION OF THE PLANETS, PART III

By Gerard P. Kuiper

Chemical evidence. Chemical information, like evidence from celestial mechanics, hydrodynamics, and astrophysics must play its role in a subject where information is woefully incomplete; and, ideally, all this information must be considered together. It seems, however, that in practice at least a partial separation of the problems is possible, which leads to a considerable simplification.

In this connection it is important to know whether each planet formed from a proto-planet of *cosmic* composition or whether *sedimentation* in the solar nebula previous to the break-up could have changed this. Sedimentation will, of course, take place toward the plane of symmetry; but in principle it must take place toward the sun also. The density and the temperature of the solar nebula decrease outwards, and therefore the gas pressure does likewise. The pressure gradient and the centrifugal force are outward forces which, for the gas, balance the attraction by the sun. For the condensate the pressure gradient (buoyancy force) is negligible and the particles will begin to fall in toward the sun. In so doing they acquire a velocity in excess of the surrounding gas, lose momentum by friction, and must continue to spiral in, as long as the solar nebula exists. Quantitatively, however, the effect is negligible, as will be shown. The maximum effect will be found for a nebula at the Roche density, $\rho = \rho_0 r^{-3}$. From this relation and with $T = 40°$K. and $\mu = 2.4$, one finds at 1 astr. unit $dp/dr = 2 \times 10^{-23}$ c.g.s, while the solar attraction is 0.6 c.g.s. The ratio, called s, is 3×10^{-23}. The particle will now seek a smaller orbit, conserving angular momentum, from which one finds $\Delta r/r = -s$ (because gravity will then increase as $\Delta g/g = 2s$ and the centrifugal force as $\Delta f/f = 3s$). Thereupon the particle will experience a resisting force owing to its excess velocity Δv over the surrounding gas, such that $\Delta v/v = s/2$ or $\Delta v = 5 \times 10^{-17}$cm./sec. This result is independent of particle size. The resistance experienced by the particle may be found from Stokes's law. This leads to the result that a particle 1 cm. in radius would change its distance from the sun by about 1 metre in 10^7 years. Not until solar radiation, and with it the Poynting–Robertson effect, became appreciable, will sedimentation toward the sun have become important. This means that each genuine proto-planet will have started essentially with the cosmic composition and that the physical chemistry of planet condensation can be considered apart from the

hydrodynamics of proto-planet formation. The resulting planetary composition, however, will still to some extent depend on the hydrodynamical process, as is illustrated below by the comparison of Jupiter and Saturn (pp. 161, 169).

The dynamics of the solar nebula at the time of break-up has shown that the planets were born when the sun was cold, at temperatures much below the present planetary surface temperatures. This is a very different picture from that considered only a generation ago when it was thought that they condensed out of solar gases of perhaps one million degrees. That this extreme was quite contrary to geochemical evidence (such as the retention of water but the loss of neon) was pointed out by von Weizsäcker (1944, p. 322), Latimer (1950), and Urey (1951, 1952, 1954), who concluded that this evidence indicated present planetary surface temperatures rather than much higher values. Latimer and Urey also examined the composition of a cosmic cloud at 298°K. and found it to consist of the gases H_2, H_2O, CH_4, NH_3, He, Ne, etc.; and solids composed of metals, silicates, nitrides, carbides, halides, sulfides, etc. At the very low temperatures later found for the solar nebula at the time of its break up, nearly all H_2O and NH_3 will have condensed out, with H_2, CH_4, and the inert gases remaining. The snows will have greatly assisted in the accretion process in the solar nebula, leading to the comets and the asteroids; and in the sedimentation within the proto-planets, which led to the formation of the planets proper.

The compositions of sun and earth give direct proof that the encounter hypothesis is incorrect and that the solar nebula was never part of the sun proper. The upper limit for the solar deuterium to hydrogen ratio is much below the terrestrial ratio of about 1/6000, while solar lithium is also abnormally scarce. This shows that "the planetary matter was differentiated from the solar matter before the sun attained its equilibrium temperature" (Kuiper, 1952*a*, p. 319). The recent determination by Boato of the isotopic composition of the hydrogen in eleven carbonaceous chondrites, giving substantially the terrestrial ratio, generalizes this conclusion (Craig and Boato, 1955, p. 405).

Consistent with the outline for this article in the first paragraph of Part II, no attempt will be made here to discuss further the processes of condensation of planetary bodies inside the eight proto-planets; nor the condensation and resultant composition of comets and asteroids in the stable parts of the solar nebula. For this reason no analysis is included of a recent paper by Urey (1954) which in part comes to somewhat different conclusions from those presented here.

Proto-planet Masses, Gross Planetary Composition, and Stability of Solar System. So far no detailed hydrodynamical treatment of the formation of proto-planets is available to supplement the general analysis based on application of the theory of gravitational instability. Until such a detailed treatment has been made only some rather general semi-empirical data are available on the initial density distribution within the proto-planets (cf. p. 169); and on the fraction w which the proto-planet diameter occupied of the width of the ringshaped zone from which the planet drew material. The quantity w may be found for those proto-planets (the earth and Jupiter) whose masses are known independently.

The actual density distribution must be intermediate between the following two extremes: (1) proto-planets so strongly concentrated toward the centre that they may be treated as point-mass (Roche) models in the computation of the outermost closed equipotential surface which marks the boundary of the proto-planet; and (2) homogeneous disks of appropriate thickness (about 1 per cent. of the diameter). The relations between mass and radius in the two cases are given by the following interpolation formulae, derived for the range of mass ratios of interest here (Kuiper, 1951*c*; 1951*a*, p. 394; Kuiper and Johnson, 1956):

$$\log R/a = 0.318 \log m/M - 0.327 \qquad (1)$$

and

$$\log R/a = 0.30 \log m/M - 0.18. \qquad (2)$$

Here R is the mean equatorial radius of the proto-planet, a the semi-major axis of the orbit around the sun, and M and m the masses of sun and proto-planet.

In Part I it was found that almost certainly M has not changed appreciably, while no reason was found to assume that the a values had changed drastically. For two planets, the earth and Jupiter, m appears to be known reasonably well from independent data (composition and dynamical), at 480 and 20 times present planetary masses (Kuiper, 1953*d*; Rabe, 1954) although the value for the earth may be in the nature of a lower limit. The values of R and w may therefore be computed from equations (1) and (2): for the earth $R/a = 0.059$(1) or 0.093 (2); $w = 0.31$ (1) or 0.49 (2); and for Jupiter $R/a = 0.135$ (1) or 0.202 (2); $w = 0.40$ (1) or 0.60 (2). Since both extremes are improbable we estimate $R/a = 0.076 \pm 0.008$ and $w = 0.40 \pm 0.05$ for the earth; and $R/a = 0.17 \pm 0.02$ and $w = 0.50 \pm 0.05$ for Jupiter. Thus, *the proto-planets extended initially to about half of the width of the ring from which they had drawn their material.*

The computed results for the other proto-planets are collected in Table II; the arrangement is similar to that of an earlier table which it replaces (Kuiper, 1951*a*, p. 392). The first columns are self-explanatory; log

$R/a = \log \Delta/2 + \log w - \log a$, in which w (earth) was used for the terrestrial planets and w(Jupiter) for the Jovian planets; $w(1)$ was used in equation (1), w (2) in equation (2). The two sets of results were nearly identical, as was to be expected since both had to reproduce the adopted proto-planet masses for the earth and Jupiter. Table II shows the average of the two sets.

It is uncertain whether for Uranus and Neptune w(Jupiter) or w(earth) should be used. Table II is based on the former assumption; the alternative makes the proto-planet masses just *one half* those in Table II and the average mass-loss factor 75 instead of 150. The intermediate factor of 100 may be used until more is known. The value for Saturn is interesting, in that it suggests that while the proto-planet initially resembled Jupiter, it suffered a mass loss 3 times greater. The larger mass loss for Uranus than for Neptune may be computational and result from the equal partition in log a while in fact the more massive proto-Saturn would have extended its effects more than half-way. The result for Mars is actually meaningless; in reference 1953*d* it was found that Mars and Mercury formed in regions of the solar nebula somewhat *below* the critical density for which gravitational instability could set in without the help of condensation products; their formation resembles that of a dozen or so regular satellites which were hybrid structures during their formation, between genuine proto-satelites and condensations formed in the nebula by accretion.

TABLE II

Planet	log a	log a boundary	Δ log a	a boundary	Δ	log $\frac{m}{M}$	Δ log m
Mercury (aphelion)	−0.330						
		−0.24		0.58			
Venus	−0.141		0.17		0.27	−2.86	2.75
		−0.07		0.85			
Earth	0.000		0.16		0.38	−2.84	2.68**
		+0.09		1.23			
Mars	+0.183		0.18:		0.63:	(−2.72)	(3.77)
		+0.27:		1.86:			
Asteroids	+0.45±		0.28:				
		+0.55:		3.55:*			
Jupiter	+0.716		0.30:		3.5	−1.72	1.30**
		+0.85		7.1			
Saturn	+0.979		0.28		6.4	−1.72	1.82
		+1.13		13.5			
Uranus	+1.283		0.25		10.5	−2.01	2.35
		+1.38		24.			
Neptune	+1.478		0.20:		14	−2.23	2.06
		+1.58:		38			

*Present boundary about 4.0. **Adopted in computing w.

The question remains whether the predicted proto-planet masses are compatible with the information on *planetary compositions*. This will give some checks on the assumptions made regarding a and w.

Qualitatively, there appears to be good agreement. Ramsey (1951) finds Saturn to contain about 60 per cent. of hydrogen and Jupiter 80 per cent., which would indeed show that Saturn lost a larger fraction of its mass by evaporation. Proto-Jupiter had a mass about 13 times proto-earth, so that 4–5 per cent. of the present planet's mass should be silicates and metals. If Ramsey's figures were to be taken literally, 15 per cent. of Jupiter would be helium, water, methane, ammonia, and neon. One might then say that, if ¾ of the hydrogen escaped and half the intermediate material, the mass and composition of Saturn would follow. There is an additional problem, however, resulting from a comparison of Jupiter with the sun. Ignoring the solar core, where the helium content has increased during geologic time, the solar composition appears to give about 75–80 per cent. hydrogen, about 20 per cent. helium, and 1 per cent. heavier elements (Strömgren, 1953, pp. 45, 80; Henyey et al. 1955). Now the helium to hydrogen ratio cannot be larger in the sun than in Jupiter; it can be nearly equal, if Jupiter's evaporation was nearly equally efficient for the two gases, which is possible if diffusion from the interior to the exosphere was slow.

Uranus and Neptune should each contain about 5 earth masses of silicates and metals or about ½ of their mass, with the rest mostly the intermediate material and some hydrogen. This is not in contradiction with published data (Ramsey, 1951) and suggests, moreover, that future analyses might take account of the expected content of heavy elements based on the theory of planetary origin. Since the density of Uranus is less than that of Neptune, proto-Uranus may have been somewhat less massive than proto-Neptune, contrary to the relation shown in Table II. Proto-Venus comes out nearly equal to proto-earth as it should on the basis of composition.

It is concluded that the composition data do not suggest any serious modification of the proto-planet masses, and that therefore *no large changes are indicated for the a and w values used*. The masses of Uranus and Neptune suggest *minor* changes in the relative distances of these planets and a(Saturn) may also be changed slightly without violation of present data. If Saturn's distance were initially somewhat larger, the computed proto-planet masses of Saturn to Neptune would decrease since the width of the zone of Jupiter would increase and w (Jupiter) decrease for a fixed assumed proto-planet mass. A 10 per cent. shift in Saturn, to 10.5 astr. units, will decrease w(Jupiter) also by 10 per cent.

and changes the last three entries in Table II to 1.62, 2.14, and 1.92. This discussion refers to a question raised in Part I.

Mass Distribution in the Solar Nebula. On the assumption that the proto-planets collected essentially all the mass of the solar nebula in their respective zones, the mass distribution of the nebula may be determined from the data in Table II, supplemented by estimates of the initial mass present in the zones of Mercury, Mars, the asteroids, and the comets. the total mass of the solar nebular so found is about 0.06 $M_\odot$ and the radial distribution is shown in figure 2. The absolute amounts are dependent on the adopted masses of proto-Jupiter and proto-earth, and will be subject to revision with increased information on these bodies.

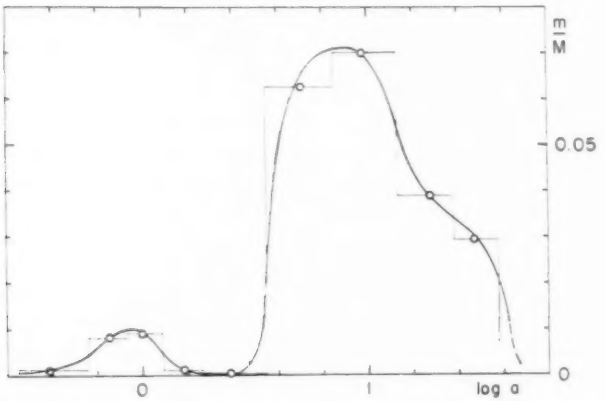

FIG. 2—Mass distribution in solar nebula just prior to break up into proto-planets. *Abscissae*: log *a*, if *a* is expressed in astronomical units. *Ordinates*: nebular mass in solar masses per unit interval in log *a*.

The question now arises whether the radial mass distribution found is actually possible hydrodynamically, or whether the steep gradients should have been wiped out. Consider the steep gradient at 4 astr. units and assume that the thickness of the nebula was such that the density in the plane of symmetry was the Roche density (about 10^{-8}c.g.s) at 4 astr. units and zero at 3.4 astr. units. Then $\Delta\rho = 10^{-8}$ c.g.s., $\Delta r = 10^{13}$ cm., or $d\rho/dr = 10^{-21}$ c.g.s. Let $T = 30°$K., $\mu = 2.4$; the $dp/dr = 10^{-12}$c.g.s. and the ratio of the pressure gradient to solar attraction is 2.5×10^{-11}. If one now starts with a condition in which the centrifugal force just balances gravity, then the pressure gradient will cause the gas

to be displaced radially until conservation of angular momentum causes the centrifugal force to balance gravity plus the pressure gradient. The displacement is readily found to be 15 metres, entirely negligible. In other words, the pressure gradients are so minute that very small dynamical adjustments can compensate for them. What will be of much greater importance is the action of self-gravity in the nebula, leading eventually to the formation of proto-planets.

Are planetary systems forming at present? One might inquire whether there are astronomical objects observable now which resemble the solar nebula; a much desired empirical check on some of the deductions might thus result. It is now known, of course, that the spiral nebulae are very different. Two classes of objects appear promising, the *globules* and the *T Tauri stars*. The globules (Bok, 1955; Minkowski, 1955) are dark, nearly circular patches occasionally seen projected on a bright nebulous background. The smallest found has been estimated to be about 7000 astr. units in diameter, 100 times the solar nebula. These dark globules might, except for scale, resemble the solar nebula before its break-up. The mechanism of the T Tauri emissions (Joy, 1945, 1949; Herbig, 1952) is still unknown and hence the relation to the solar nebula. Since the central stars are visible, however, one might think either of the stage in which the star lost angular momentum to an ionized inner part of a surrounding nebula; or of the subsequent phase, in which the central star has attained its equilibrium brightness and is dissipating the nebula. If one observed a nebulous emission patch without a visible central star, as apparently has also happened (Herbig, 1955), one would think of the phase preceding the formation of the solar nebula, during which a rapid gravitational collapse took place. It seems possible, therefore, that all four stages of development of the solar nebula can, in principle, be studied empirically, and this prospect is exciting.

To recapitulate, the four stages are: (1) gravitational collapse until angular momentum arrests process; (2) quiescent period of slow internal rearrangement of nebular matter, which by now is disk-shaped and in fairly rapid rotation; cooling of nebula by radiation to space; onset of gravitational instability in densest parts; (3) central star becomes luminous; interior of nebula becomes ionized; angular velocity of star reduced by magnetic coupling to ionized nebula in contact with it; (4) central star attains full brightness and nebula is dissipated. If process (4) should occur before (3) has run its course, a rapidly rotating star must result. This would be most likely to happen for massive main-sequence stars, whose time scale of contraction is shortest; this is so

because the energy released under gravitational contraction increases as M^2/R, i.e. by less than the square of the mass, while the luminosity increases roughly as the cube of the mass. As a result, O and B stars may lose their nebula *before* rotation is much reduced. Qualitatively, this fits the facts on stellar rotation very well (Struve, 1949; Slettebak, 1954; Herbig and Spalding, 1955; Sandage, 1955).

Nature and Frequency of Other Planetary Systems. The preceding considerations enable one to make some predictions on the nature of other planetary sytems. For the early-type stars less time was available for planetary condensation than for the solar system while the subsequent evaporation process was much more intense. This will have favoured the production of almost bare planets, of the terrestrial type. However, one might doubt whether these planets had time to develop life; the stars went through their evolutionary cycle too fast, first getting bright and thereupon very faint all within 10^8 years or so. For red-dwarf stars the other extreme holds. Contraction and evolution were very slow, condensation of planets had much more time (10^8–10^9 years), subsequent evaporation of the proto-planet envelopes was feeble, and giant planets with very extensive envelopes probably resulted, retaining a great excess of hydrogen. Our own planetary system, associated with an intermediate-

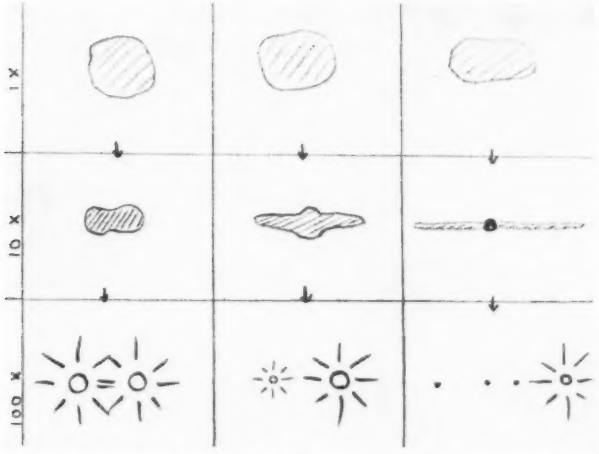

FIG. 3—Three possible developments of proto-stars, forming, respectively, (1) binary star with equal components, (2) binary star with unequal components, and (3) planetary system. Note change of scale between consecutive stages.

type star, has four planets of each class, though none of the extreme proto-planet variety.

The similar origin of binary stars and planets, illustrated in figure 3, makes it further possible to estimate the *frequency* of planetary systems in space. For all but the most massive main-sequence stars, where the relation may be somewhat different, one can summarize the frequency of mass ratios in binaries by the statement that if one combines the components of each binary into a single mass, then one recovers the original set of binaries, statistically speaking, by dividing the combined masses in a random manner (by mass, not by radius). Because of observational restrictions this relation is not known empirically to hold for divisions more extreme than about 0.1–0.9, but we shall probably obtain a fair estimate even in such cases. Since the mass of the solar nebula, in order to produce any planets at all, had to exceed about 0.01 sun and was, actually, about 0.06 sun, and since the secondary mass cannot be more than 0.5 of the total, we find that at most some 10 per cent. of the masses that divided could have produced planets. Since the masses that divided are probably well over 50 per cent. of the total (90 per cent. may be

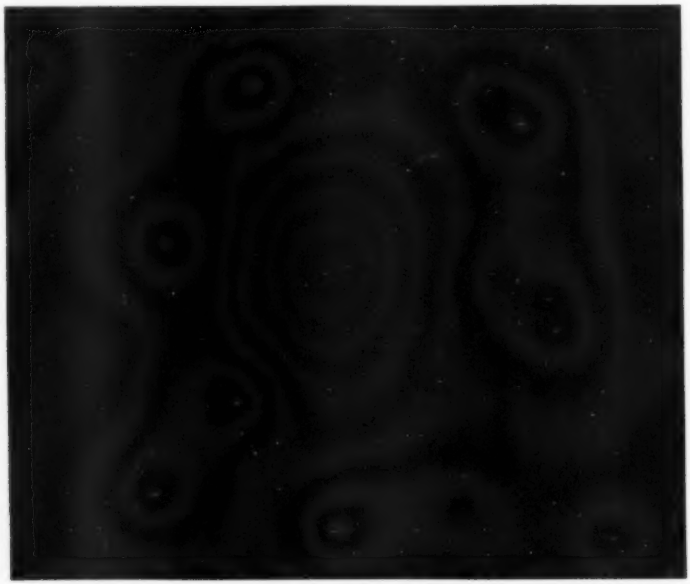

FIG. 4—*Above*: vertical cross section of solar nebula before break up (schematic). *Below*: appearance just after break up.

closer) and since a nebula equally massive as the solar nebula, but more concentrated radially, would have produced a small star, we estimate that 1–10 per cent. of the main-sequence stars are attended by planets. This means a number of 10^9–10^{10} in our galaxy alone.

The great frequency of planetary systems here predicted appears comforting to this writer when contemplating our own system—which apparently is no freak of nature any more than the sun itself. But in the past, comfort has been derived from the opposite position. T. C. Chamberlain (1928), who concluded from the extreme improbability of stellar encounters that the planetary system would be almost unique in the galaxy, wrote: "Our planetary family had an aristocratic birth. It was no everyday affair . . .". It is a worthy problem to consider how in such a case *a priori* probabilities should be treated.

Dynamical Consequences of Proto-planet Evaporation. Figure 4 sketches the planetary system when the sun was still dark. A profound change occurred when the sun "turned on". The brightening of the sun, in the last phases of the contraction period, was of course gradual; yet, astronomically speaking, it was a rather sudden event, and it all but destroyed the proto-planets. The first action was to ionize the most tenuous parts

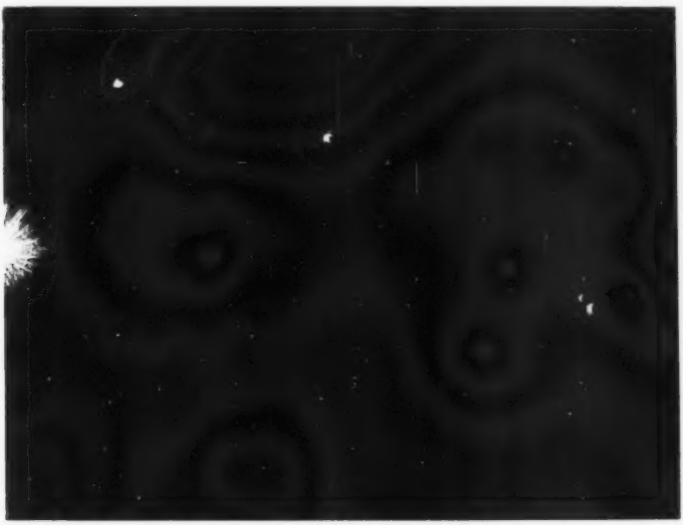

FIG. 6—Hypothetical appearance of three nearest proto-planets after sun attained full brightness.

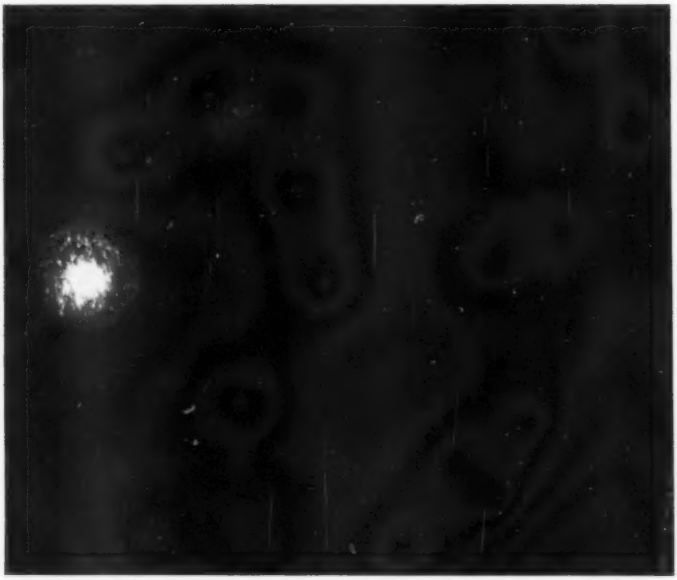

FIG. 5.—Proto-sun, faintly luminous, and two proto-planets.

of whatever remained of the solar nebula; whereupon these parts were promptly driven off into interstellar space by solar corpuscular radiation. This "radiative erosion" continued until the entire interplanetary space was cleared. Thereupon the action commenced on the outer parts of the proto-planets. They developed exospheres with temperatures nearly 10 times the present equilibrium surface temperatures, as is still true today (the mean equilibrium surface temperature of the earth is 250°K., the exosphere probably 1500–2000°K.). The velocities of escape were small compared to the present values computed for the planetary surfaces, and evaporation to interplanetary space was very efficient. Ultra-violet and corpuscular radiations drove these materials out of the planetary system before they accumulated. Figures 5 and 6 illustrate the probable appearance of the solar neighbourhood just before and just after the sun attained full brightness.* For details the reader is referred to three papers mentioned before (Kuiper, 1951*b*, 1952*a*, 1953*c*); the first shows

*Figures 3–6 were made for a lecture on the origin of the solar system given at the Franklin Institute at Philadelphia on April 16, 1952, at which the author was the recipient of the Rittenhouse medal. The lecture has remained unpublished.

shows that evaporation and not equatorial instability led to the enormous mass losses of the proto-planets, and that the energy for this evaporation came from the sun, not the planet; the second considers the loss of the terrestrial proto-atmosphere and, briefly, the envelopes of the Jovian planets; and the third considers the physics and dynamics of the evaporation process of solar nebula and, very briefly, the proto-planets.

For a given planet, the present composition is strongly dependent upon the initial mass distribution of the proto-planet and can therefore be used to study this distribution. This is seen as follows. The evaporation rate depends on the molecular weight μ and the temperature T of the planetary exosphere, and further on the velocity of escape, i.e. on M/R. Now, for a strongly concentrated mass, M/R will vary as R^{-1} as R decreases by evaporation, while for a uniform disk it will vary nearly as R^{+1}. On the first model, evaporation will be limited to smaller and smaller μ; on the second, it will include all gases up to a larger and larger μ. The starting values of μ for the Jovian proto-planets were estimated before (Kuiper, 1952*a*, pp. 345–46); no important revisions are indicated by the present discussion. They show that the present Jovian planets could indeed have formed from the proto-planets discussed if these were built on a model intermediate between the two extremes mentioned. The greater mass loss for Saturn than for Jupiter, derived before, requires proto-Saturn to have been less concentrated than proto-Jupiter. This appears consistent with the somewhat greater extension of Saturn's system of regular satellites.

The loss of nearly all the proto-planet mass was not the only consequence of the evaporation process. *It appears to have been the principal cause for the planetary obliquities to have increased* from the small, random, initial values of less than 5°, to be expected from the mutual inclinations of consecutive planetary orbits, to the present values. This happened because the evaporation was concentrated around the hottest point of the proto-planet, the subsolar point, which was not, in general, on the equator. If one first considers the simple case of a spherical planet with all evaporation concentrated around the subsolar point, then one finds that the angular momentum lost to the planet will be represented by a vector, issuing from the planetary centre, that describes a circular cone with uniform velocity, having half the period of the planetary year. This cone is contained between the pole of rotation and the normal to the planetary orbit, also drawn through the planetary centre. Apart from a minor nutation, this will result in the angular-momentum vector representing the planetary rotation to become both shorter and more tilted. This problem is dealt with more fully elsewhere (Kuiper, 1953*d*).

It appears that a satisfactory explanation is obtained of the general magnitude of the present obliquities except for Uranus, where an additional effect must have been operative. Solar tidal friction operating on flattened disks will also increase the obliquity (Kuiper, 1951*a*), but this process is less effective than evaporation. However, it is capable to leading to obliquities in excess of 90°, which is not true for evaporation.

An indirect effect of the evaporation is equally unexpected. A planet attended by a satellite, decreasing its mass by the factor D, will cause an increase in the radius of the satellite orbit by the same factor D. We have seen that D may be as large as 100–1000 for the terrestrial planets and 10–100 for the Jovian planets. As the mass of the planet decreases, its radius of action r_A in the tidal field of the sun decreases also, roughly as $D^{1/3}$. If the radii of the satellite orbits, a, are expressed in terms of r_A, the ratio a/r_A will increase roughly as $D^{4/3}$ and may surpass unity, *causing the satellite to be deposited into interplanetary space.* Three possible courses may ensue: (*a*) the satellite is recaptured by the parent proto-planet; or, continued mass decrease by the proto-planet may press the former satellite into (b) a Trojan-type orbit around the sun (stable case of the restricted three-body problem); or (c) a Hidalgo-type orbit around the sun. For further details the reader is referred to the original papers (Kuiper, 1951*c*, 1952*b*, 1953*a*, 1953*d*, 1953*e*).

Possibility (a) gives an adequate explanation of the 12 irregular satellites, half of which have retrograde orbits. The dynamics of the Trojans as former satellites of Jupiter has been investigated in detail by Rabe (1954) who derived the important result that the Trojan orbits can be explained if Jupiter's mass decreased by the factor 20 since the first Trojan was shed as a satellite into interplanetary space. A similar analysis for Hidalgo has not yet been carried out and may prove too difficult because of planetary perturbations other than Jupiter's over the enormous interval of 4–5 billion years (see discussion accompanying Table I). In the differential motions of the Trojans with respect to Jupiter such perturbations appear to have little effect so that one is dealing almost with a pure restricted three-body problem.

The Case of Pluto. Pluto is a very curious planet. Its orbit nearly intersects with that of Neptune, which appears entirely incompatible with the assumption that Pluto has originated as a proto-planet. The only reservation is that Pluto may have been perturbed afterward by a passing star. From stellar numbers and velocities the probability of such an event during geologic time is found to be about 10^{-5}; the *a posteriori* probability is even smaller because Neptune was apparently not perturbed, its

orbit being nearly a perfect circle now. Pluto could not have formed by accretion; then its size would have been cometary instead (1–10 km. in diameter); furthermore, this would still not explain the orbit.

The fact that Pluto's orbit is similar to Hidalgo's appears to afford a clue. In both cases the inclination and the eccentricity are large; the semi-major axis is somewhat larger than that of the nearest major planet; and the orbit nearly intersects with the orbit of that planet. If Pluto originated as a satellite of Neptune, however, it would be expected to have a long period of rotation, at least if its original distance from the planet was less than about 60 planetary radii, the distance of Iapetus from Saturn, where synchronization of rotation and revolution still occurs. The only possibility of finding Pluto's period of rotation and thereby testing the hypothesis of Pluto's origin, was by photometry, if the planet indeed would show variations (Kuiper, 1953*a*, p. 1156). Photometric studies were begun in 1952 and 1953 to test this. Short-period variations were found to be absent, but variation with an as yet undetermined longer period was established in 1953. The amplitude was found to be 0.10 mag. Since then Walker and Hardie (1955) at the Mount Wilson and Lowell Observatories have accumulated additional observations which enabled them to determine the period, 6.4 days.

This result is gratifying because it seems decisive. The conclusion so reached regarding Pluto's origin as a satellite of Neptune should not be confused with Lyttleton's (1936) hypothesis that Pluto and Triton were initially both satellites of Neptune and then had a close encounter, which caused Pluto to leave the system and Triton to become retrograde. There is no reason to suppose that an encounter between regular satellites has ever occurred; and there are five retrograde satellites other than Triton.

Pluto's origin as a former satellite of Neptune, lost when the sun became bright and the proto-planets lost mass by evaporation, may be further studied on the basis of the Jacobi constant C of Pluto in the system sun-Neptune. Rabe (personal communication) has computed C to be 2.901. It can be readily shown by the method developed by Rabe (1954) that C cannot be due to the decrease of Neptune's mass after Pluto's release; the departure from $C = 3$ is too great. However, a loss of 0.03 solar masses in the interior of the solar system subsequent to Pluto's release wil explain C; this mass loss is compatible with the total loss of 0.04 solar masses by Jupiter and Saturn together (cf. Table II), to which must be added small mass losses by the sun and the other interior planets. The nature of Pluto's orbit is thus found to be a direct consequence of the mode of origin of the planetary system as developed above (cf. also Kuiper and Rabe, *Astrophysical Journal*, in press).

The value of the rotational period requires more detailed study. If one merely assumes that Pluto acquired that period as a satellite at a given distance from Neptune and thereupon retained it without change, then one finds that Neptune's mass had to decrease by the factor 40 before Pluto became independent. This is compatible with previous results on proto-Neptune, but a detailed analysis of the changing period of rotation must be made as the satellite moves out. Next, the period of rotation of Hidalgo must be determined, to fix its original distance from Jupiter—if indeed it formed as a satellite. Finally, the periods of rotation of the Trojans must be found, if possible, which will permit one to replace the minimum mass loss of Jupiter by the *actual* one (because it would show how much mass Jupiter had to lose before it could shed the Trojan in question). The *total* mass loss should be found from the asteroids, however, and is still found to be a factor of 20 (Rabe, 1956).

Summary and Conclusions. The planets formed from a solar nebula. This nebula was shown to have been formed by the contracting sun itself; it was not captured subsequently. The temperature in the nebula dropped to about 40°K. at 1 astr. unit and less farther out before gravitational instability set in and broke up the nebula into proto-planets; at that time turbulence had decayed to near insignificance. The proto-planet masses, dimensions, and orbital radii were almost entirely determined by the local surfare density in the nebula and were essentially independent of whatever density fluctuations initiated the break-up. There were two regions of instability, each forming four planets, separated by a stable region that formed asteroids by accretion; outside proto-Neptune, another stable region occurred in which accretion formed comets. The two smallest planets, Mercury and Mars formed late, and condensation in the nebula played an important role in the proto-planet formation. Each proto-planet developed at its centre a planetary body by condensation and sedimentation; and, farther out, minor satellites in the gravitationally stable part of the envelope. After the sun grew bright, interplanetary space gradually became an HII region and got cleared out, upon which the evaporation of the proto-planet envelopes began; this process lasted nearly 10^9 years. The evaporation increased the planetary obliquities to their modern values except for Uranus whose obliquity seems larger than can be accounted for by evaporation and tidal friction; it also somewhat increased the orbital eccentricities; and it caused the more distant satellites to be dropped into interplanetary space, from where they could be recaptured by collisions with the parent proto-planet into irregular satellites, or be pressed into orbits of the Trojan type, or into orbits of

the Hidalgo and Pluto type. During the later stages each of the outer proto-planets had collected appreciable quantities of condensate near its equatorial plane which slowly spiralled inward toward the centre and in time led to gravitational instability and formation of regular satellites close to the planets; subsequent planetary mass losses by evaporation were small and the regular satellites did therefore not increase appreciably their distances from the central bodies. Because strong tidal friction prevented the proto-satellites from rotating faster than with their orbital periods, they could not form flat disks themselves and produce a *third* generation of bodies, satellites to satellites. Solar tidal friction similarly prevented Mercury and Venus from acquiring regular satellites. The earth-moon system is a double planet, resembling, on a small scale, the formation of a binary star, not a planetary system. Its history is entirely abnormal in the solar system. Neptune should have formed a system of regular satellites as the other outer planets did; but this was apparently prevented by the fact that Triton was recaptured in a *retrograde* orbit. This caused Triton to spiral inward toward Neptune as long as the envelope existed; it probably acquired part of the condensate.

As indicated before, this article will not consider the largely undeveloped subject of *internal* proto-planet evolution, with its many interlacing problems, such as the initial mass and velocity distributions within the proto-planets; effects of solar tidal friction and of turbulence on the radial support of the envelope; condensation and sedimentation in the presumably turbulent envelope; formation, numbers, and sizes of minor satellites; evaporation of gases from the exosphere; role of diffusion in the envelope and effects on subsequent planetary composition; losses of solids to interplanetary space owing to the mass decrease of the proto-planet; origin of satellite gaps just outside the systems of regular satellites; detailed formation of the regular satellite systems; formation and retention of sediment rings; periods of planetary rotation; conditions leading to formation of the double planet, earth-moon; internal development and chemical fractionation of planetary bodies; detailed planetary compositions.

We have attempted to sketch the origin and the earliest development of the planets as separate bodies, as appears consistent with present-day knowledge. The discussion has indicated where additional theoretical work is especially urgent. Perhaps it is correct to say that one now has a beginning of a theory of the origin of the solar system, presenting no known obstacles to further development. A further comment is prompted by a re-examination of earlier attempts to solve this problem. It is the surprising dependence of theoretical thinking on the contemporary

knowledge of elementary facts, facts not of origin but about the present system. This poses a warning against premature developments and shows that a vigorous campaign for the acquisition of new data over the entire front of planetary studies is essential to progress.

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*A misprint occurs in eq. (1); r and R should be interchanged.

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VARIABLE STAR NOTES
American Association of Variable Star Observers

By MARGARET W. MAYALL, *Recorder*

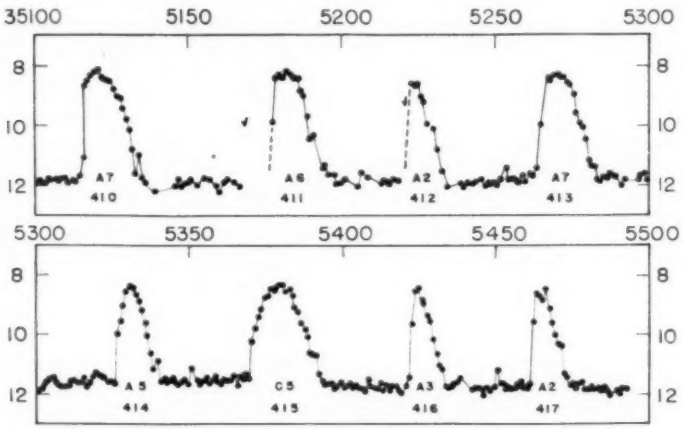
The Annual Spring Meeting of the A.A.V.S.O. was held at Cornell University on the week-end of May 18–20, 1956. Our hosts were Dr. R. William Shaw and Dr. Martha S. Carpenter of the Department of Astronomy. Thanks are also due to the other members of the astronomy department, who helped so nobly with meeting arrangements, registration and so forth, and to Dr. Carl Gartlein of the Auroral Laboratory, and the staffs of the Ionospheric and Radio Astronomy Labs who were so enthusiastic in their demonstrations of their equipment.

One of the highlights of the meeting was the Friday evening lecture by Dr. Shaw on "Interplanetary Travel and the New Astronomy." The following 22 papers were presented at the Saturday sessions: "The Light Curves of Some Long Period Variables in Scutum," Margaret Harwood; "Colours in Sun-spots," F P. Morgan; "A Proposed Programme of Visual Meteor Observing for the I.G.Y.," Peter Millman; "The Skies Through a Prism," Frank Kelly; "Top Secret Plans from the Inner Sanctum," Clinton Ford; "Auroral Work for the I.G.Y.," C. W. Gartlein; "Domed Versus Open Observatories, and Seeing Criteria," Frank DeKinder; "Prediction of the Next Sun-spot Maximum," Leith Holloway; "Annular Configurations of Sun-spots," James G. Bartlett; "Present Phase of Solar Activity," Harry L. Bondy; "A Solar Flare Indicator, Transistorized," David Warshaw; "The Evolution of Sun-spots," Thomas A. Cragg; "Work of the Cornell Radio Astronomy Lab," Edward Schiffmacher; "What Goes On," Newton Mayall; "A Peculiar Aurora in 1941," Gunnar Darsenius; "Are Martian Canals Real?" Paul Gernant; "The Value and Uses of Planetariums," George Lovi; "Predicted Mean Light Curves of Nine Long Period Variables," Margaret Mayall; "Picking a Nova Field and Observing It," George Diedrich; "Why Not Try Meteor Photography?" Edward Majden; "New Solar Laboratory and Telescope for Northwestern Observatory," Ben Parmenter; "Some Ideas Concerning the Expanding Universe," William Raine. Abstracts of these papers are being edited by Newton Mayall, and will be distributed to members in the near future. A limited number of additional copies will be available to others upon request (please send stamped envelope).

The Council elected 31 new members to the A.A.V.S.O. and approved the transfer of Dr. Helen Sawyer Hogg from annual membership to sustaining. The new members are as follows: Jim Arnold, Texas; Mrs. Dorothy E. Beetle, Wyoming; David G. Black, Ohio; Phillip W. Budine, New York; Dr. Wallace Byrd, Oklahoma; Walter J. Cornett, Pennsylvania; Dr. Armin J. Deutsch, California; Georges Emond, Sainte Therese, Quebec; Paul Gernant, Michigan; Charles M. Good, Montreal; Hans D. Isenberg, Illinois; Lionel St. Elmo Jones, Jamaica, B.W.I.; A. S. Kane, North Dakota; Kenneth A. Klementis, Ohio; Edward Majden, Saskatchewan; Stanley Mallory, Texas; Northwestern Observatory (sustaining), Washington; Bernard W. Powell, Connecticut; The Prime Focus Club, Ohio; James B. Pritchett, North Carolina; William L. Raine, Tennessee; Robert R. Huge, Ohio; Terry E. Schmidt, Illinois; Albert P. Sharpless,

Florida; William F. Smysor, Jr., Ohio; Samuel L. Terry, Pennsylvania; R. P. VanZandt, Illinois; Roy Wagner, Ohio; Whittier Astronomical Society, California; Miss Isabel K. Williamson, Montreal; James C. Wolfe, Pennsylvania.

At the Society Dinner, the Recorder and her husband were delightfully surprised and honoured by being presented with the association's 14th Merit Award, in the form of a beautiful scroll, delineated and illuminated by Edgar M. Paulton. The citation reads: "14th Merit Award to Margaret Walton Mayall and R. Newton Mayall for their unfailing devotion to the ideals and interests of the Association during its recent years of great trial, and for their combined efforts in completing for publication the Leon Campbell Memorial Volume 'Studies of Long Period Variables.'"



Mean light curve of SS Cygni, 1955.

TABLE I

OBSERVED MAXIMA OF SS CYGNI IN 1955

No. Max.	Type	10.0 I J.D.	Diff.	Max. J.D.	Diff.	10.0 D J.D.	Diff.	Max. Mag.
410	A7	2435116	59	2435120	62	2435130	65	8.2
411	A6	5177	61	5182	62	5189	59	8.3
412	A2	5222	45	5224	42	5228	39	8.6
413	A7	5265	43	5270	46	5278	50	8.3
414	A5	5327	62	5330	60	5336	58	8.4
415	C5	5371	44	5379	49	5388	52	8.4
416	A3	5422	51	5424	45	5429	41	8.5
417	A2	5462	40	5465	41	5470	41	8.6

213843 SS *Cygni*. SS Cygni continues to be one of the most popular variable stars to observe, and during the year 1955 we received 1309 observations made by 55 observers on 304 nights. This total includes 331 observations made by eight members of the Scandinavian Astronomisk Selskab, and very kindly sent to us by Mr. Axel V. Nielsen of Aarhus, Denmark. The rising branches of maxima numbers 411 and 412

(*continued on p. 180*)

Observations received during March and April 1956: In March 3,847 were received from 59 observers, and in April 3,677 from 61, a total of 7,524 observations for the two months.

Observer	March		April		Observer	March		April	
	No. Var.	No. Ests.	No. Var.	No. Ests.		No. Var.	No. Ests.	No. Var.	No. Ests.
Adams, R. M.	48	141	62	161	de Kock, R. P.	111	372	121	555
Anderson, C. E.	79	139	23	40	Kofeod, R.	3	4	2	2
Arnold, J.	3	6	4	9	Loehde, F.	2	2	...	...
Aronowitz, C.	46	63	41	41	Maran, S. P.	75	151	67	70
Ball, A. R.	31	50	10	10	McPherson, C. A.	8	8	8	8
Beidler, H. B.	16	16	...	...	Mebius, W. G.	...	...	7	15
Berg, R.	33	59	35	39	Melville, E. C.	14	19	8	12
Bieda, S. W.	...	...	3	3	Miller, R. W.	17	17	16	18
Bonilla, T.	...	...	7	7	Montague, A. C.	17	20	16	20
Breckinridge, J.	10	16	9	15	Morgan, F. P.	17	54	21	47
Buckstaff, R. N.	5	6	8	14	Neff, J.	2	4	...	...
Carlisle, J. H.	1	3	1	2	Oravec, E. G.	159	375	200	473
Carpenter, C. B.	...	...	18	20	†Overbeek, M. D.	47	51	...	...
Charles, D. F.	4	6	17	21	Parker, P. O.	38	38	26	26
Cragg, T. A.	129	133	172	223	Pearcy, R. E.	1	1	5	5
Culp, C.	...	...	2	2	Pearlmutter, A. E.	...	...	80	211
*Darsenius, G. O.	14	35	16	139	Peltier, L. C.	21	84	17	81
Deemer, R.	10	15	...	...	Pilcher, F.	12	14	7	7
Diedrich, DeL.	1	1	1	1	Pivonka, R. J.	...	...	2	3
Diedrich, G.	8	17	8	18	Renner, C. J.	108	116	...	...
Elias, D. P.	41	47	...	...	Richards, M.	1	1	...	...
Erpenstein, O. M.	13	58	13	35	Rizzo, P. V.	20	32	19	25
Fernald, C. F.	147	250	127	255	Rosebrugh, D. W.	12	74	11	71
Ford, C. B.	95	111	57	57	Royer, Ronald	18	30	20	30
Gleason, W. S.	1	1	...	...	Schultz, G. W.	13	21	15	15
Glenn, W. H.	10	16	19	44	Segers, C. L.	19	75	21	60
Goldenblatt, P. P.	63	147	52	121	Skaritka, P.	87	132	61	106
Goodsell, J. G.	2	2	3	3	Sharpless, A. P.	6	7	...	...
Halbach, E. A.	14	15	...	...	Solomon, L.	100	122	3	5
Hartmann, F.	126	134	124	149	Taboada, D.	130	244	95	141
Haslop, N.	...	...	4	4	‡Venter, S. C.	74	194	...	...
Hein, G.	20	41	28	49	Watson, P. S.	...	...	28	44
Houston, W. S.	...	...	1	1	Wend, Richard	...	...	1	1
James, R.	26	26	1	1	Witalis, R.	...	...	1	1
Kelly, F. J.	10	10	10	13	Wolfe, J. C.	...	...	1	36
Kimball, M.	20	20	11	14	Wyckoff, J.	...	...	7	11
Knowles, J. H.	...	...	18	67	Zelvin, J.	1	1	...	...

*Plus 15^m AD Leo; $2^h\ 53^m$ SZ UMa; $2^h\ 10^m$ V371 Ori; $5^h\ 33^m$ YZ CMi; $1^h\ 9^m + 55°$ 1823

†Plus $1^h\ 40^m$ UV Ceti

‡Plus 1^h UV Cet; 3^h AE Aqr

are defined by the S.A.S. observations, with the help of some "variable not seen" observations by D. W. Rosebrugh. When SS Cygni passes behind the sun and becomes visible in the morning sky, few observers stay up long enough or rise early enough to observe it, and any observations (even "fainter than 9.0") may be very valuable.

Eight maxima were observed during the year, all but one being of type A, with a very steep rise and slightly slower decline. The widths at the half-way point (10.0 magnitude) range from six days to 17 days. The light curve and the table of data of the observed maxima are continuations of the curve and table for 1954 published in these Notes for May–June 1955. (This JOURNAL, vol. 49, no. 3, p. 119.) As in the past, the maxima are numbered consecutively from the first maximum after the discovery of the variable in 1896. The second column in the table lists the type of maximum according to Leon Campbell's classification. The columns headed "10.0 I" and "10.0 D" give the Julian Day for magnitude 10.0 on the increasing and decreasing branches of the light curve, respectively.

The mean interval between maxima of SS Cygni was 50.9 days in 1955. The mean for all 417 maxima since 1896 is 51.9 days.

Nova Search Report: The following six observers searched their areas for the number of area-nights as shown after their name. March observations and then April, 1956, follow each name.

RICHARD BATES, 0, 2; JAMES BRECKINRIDGE, 15, 15; DELORNE DIEDRICH, 5, 1; GEORGE DIEDRICH, 18, 8; NORMAN HASLOP, 2, 0; LOUIS RICK, 12, 8.

A.A.V.S.O. Headquarters,
4 Brattle Street,
Cambridge 38, Massachusetts,
May 1956.

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METEOR NEWS

By Peter M. Millman, *National Research Council, Ottawa*

Photographic Meteor Spectra (Appendix 4)

Following an established procedure I am listing here all photographic meteor spectra of which I have knowledge and which have not been included in previous appendices (see the Journal vol. 46, p. 121, 1952; vol. 47, p. 217, 1953; vol. 48, p. 225, 1954; and vol. 49, p. 169, 1955). The first column gives the reference number of the spectrum, the next six columns the universal date and time. Association with an annual major shower appears next followed by the location of the camera and the organization responsible for the programme. Last we have published references to these spectra.

I have just received news of the activity in this field in the U.S.S.R. and Czechoslovakia. Dr. Astapovich, Director of the Ashkabad Astrophysical Laboratory, has published a list of all Russian meteor spectra (28). This list contains 35 spectra taken between 1904 and 1953. Only 12 have appeared previously in my world list so the remaining 23 have been assigned numbers here, commencing with No. 151. Most of these 23 are fairly faint spectra and show detail of between 2 and 11 lines. Practically all have been visually observed and will be useful in statistical studies. Eight spectra were secured in Czechoslovakia during the Perseid observations of 1953. Bumba and Valnicek have published a preliminary study of these (29), and are planning a more complete investigation as a second part to their paper.

Mr. W. B. Ridley, Director of the Meteor Section of the B.A.A., has been very active in meteor photography recently. He has photographed 6 spectra at his station near London. One of these, No. 150, is particularly fine and shows a detail of some 50 lines.

Meteor photography at the Meanook-Newbrook meteor observatories in Alberta continued under the direction of the Dominion Observatory in Ottawa. This work is carried out by Messrs. A. A. Griffin, J. M. Grant, and D. Corness. The spectra secured at the Metcalfe Road Field Station near Ottawa were obtained on the combined National Research Council-Dominion Observatory meteor programme. Although a considerable quantity of infra-red film was exposed during these observations, no new infra-red spectra were secured in 1955.

Professor J. A. Russell and his co-workers have published a reduction

LIST OF PHOTOGRAPHIC METEOR SPECTRA (APPENDIX 4)

No.	Date y	m	d	G.C.T. h	m	s	Shower	Location (observatory)	Ref.
149	1952	8	11	5	31	02		Metcalfe Rd., Ont. (D.O.)	
150	1954	10	29	22	50		T	Barnes, S.W. 13 (W. B. Ridley)	
151	1938	9	19					Stalinabad Obs., U.S.S.R.	28
152		9	19					" " "	"
153	1939	9	20					" " "	"
154	1940	8	13				P	" " "	"
155	1951	4	20				Y	Ashkabad Obs., U.S.S.R.	"
156		8	11				D	" " "	"
157		8	11					" " "	"
158		8	11				P	" " "	"
159		8	12				P	" " "	"
160		8	12					" " "	"
161		8	13					Ashkabad Obs., U.S.S.R.	"
162		8	30					" " "	"
163		8	30					" " "	"
164		8	30					" " "	"
165	1953	5	12					Odessa Obs., U.S.S.R.	"
166		7	20					" " "	"
167		8	9				P	" " "	"
168		8					P	Simferopol, U.S.S.R. (V.A.G.O.)	"
169							P	" " "	"
170							P	" " "	"
171		12	13				G	Odessa Obs., U.S.S.R.	28
172		12	13				G	" " "	"
173		12	13				G	" " "	"
174		8	2				P	Ast. Inst. Ondrejov, Czechoslovakia	29
175		8	9				P	" " " "	"
176		8	10				P	" " " "	"
177		8	11				P	" " " "	"
178		8	11				P	" " " "	"
179		8	11				P	" " " "	"
180		8	11				P	" " " "	"
181		8	12				P	Ast. Inst. Ondrejov, Czechoslovakia	29
182		4	23	0	59	30	Y	Barnes, S.W. 13, (W.B. Ridley)	
183	1955	8	12	2	47	52	P	Metcalfe Rd., Ont. (NRC-DO)	
184		8	12	6	38	30	P	" " " "	

LIST OF PHOTOGRAPHIC METEOR SPECTRA (APPENDIX 4)—*Continued*

No.	Date y	m	d	G.C.T. h	m	s	Shower	Location (observatory)	Ref.
185		8	12	23	22		P	Barnes, S.W. 13, (W.B. Ridley)	
186		8	13	0	10	30	P	" " "	
187		8	13	6	37	40		Regina, Sask. (R.A.S.)	30
188		8	14	7	35	*	P	Meanook, Alta. (D.O.)	
189		8	15	8	15	50	P	Metcalfe Rd., Ont. (N.R.C.-D.O.)	
190		10	20	7	53	35		Meanook-Newbrook, Alta., (D.O.)	
191		10	23	6	52	*		Meanook, Alta., (D.O.)	
192		10	27	12	39	22		Meanook-Newbrook, Alta. (D.O.)	
193		12	15	0	03	30	G	Barnes, S.W. 13 (W.B. Ridley)	
194		12	15	0	07	30	G	Barnes, S.W. 13 (W.B. Ridley)	

Abbreviations—

D Delta Aquarid
G Geminid
P Perseid
T Taurid
Y Lyrid

D.O. Dominion Observatory
N.R.C. National Research Council
R.A.S. Regina Astronomical Society
V.A.G.O. All-Union Astro-Geodetic Society

*Indicates middle of exposure.

of their fine 1953 Geminid spectrum, No. 140. Over 150 features were measured and ten different elements identified (31). As reported earlier in the JOURNAL (30), the Regina Astronomical Society made a good start in meteor spectroscopy by securing Spectrum No. 179.

It is a pleasure to record this growing interest and widespread success in the photography of meteor spectra. I should very much appreciate being informed of any additional spectra which have been missed from these lists.

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REVIEW OF PUBLICATIONS

Principes Fondamentaux de Classification Stellaire edited by M. Schatzman. Pages 190; 6½ × 9½ in. Paris, Centre National de la Recherche Scientifique, 1955. Price 1,200 francs.

In this book are published, in French, fifteen papers presented at an international colloquium held at the Astrophysical Institute of Paris under the sponsorship of the Centre National de la Recherche Scientifique. In addition to the papers themselves, this book includes the discussions following each paper and also a few other short notes.

The title of this book may be found misleading by some because not only problems of stellar classification but also other important related problems are discussed. The content of the book is best described by mentioning some of the articles in it.

The first half of the book is devoted almost entirely to actual stellar classification methods and problems. Deutsch deals with the classification of the spectra of cluster stars, including the classification of the peculiar spectra found in some globular clusters. Nassau outlines classification methods which can be used for very cool stars. The classification method which involves the measurement of the Balmer discontinuity and some extensions of this method are discussed by Barbier and Chalonge. Strömgren outlines the very accurate photoelectric methods which he has used for the F-type stars. The paper by Parenago draws attention to the great amount of work done by Russian astronomers in the field of stellar classification.

The remainder of the book contains articles on the interpretation and analysis of stellar spectra. One article by Pecker deals with the theoretical analysis of various spectral classification criteria such as the Balmer discontinuity and the breadths of hydrogen lines. Another paper by Neven gives model-atmosphere calculations for four B-type stars. He also discusses the abundances of helium in these stars. Of particular interest is an article by de Jager in which he reviews the various methods used for abundance determinations and compares the values obtained.

The articles mentioned above give a good idea of the subject matter dealt with. The book should prove very valuable to those who want to know the many and varied ways in which problems of stellar classification are being attacked by the leading astronomers in this field.

J. B. O.

Studies of Long Period Variables by Leon Campbell, prepared for publication by Margaret Walton Mayall. Pages xi plus 247; 9¼ × 11¾ in. Cambridge, American Association of Variable Star Observers, 1955.

This volume contains observational data for some 390 long period variables, and is based on several hundred thousand observations made from 1921 to 1949 by the members of the American Association of Variable Star Observers. The dates of maxima and minima between 1921 and 1949 and the brightness of the stars at these times are listed in the first part of the book; in the second part are given mean light curves for all the stars. Much of this material had been prepared by Mr. Campbell before his death in 1951. The completion of the descriptions of the variables and the supervising of the drawing of the mean light curves for publication has been done by Mrs. Margaret Mayall, well known to readers of this JOURNAL as the author of "Variable Star Notes". The book contains a wealth of material which will be valuable for many research studies.

R. J. N.

Astronomischer Jahresbericht, vol. 53, edited by Walter F. Wislicenus. Pages LXII plus 468; 5¾ × 9¾ in. Berlin, Walter de Gruyter and Co., 1955. Price DM 40.

This annual publication lists and gives abstracts in German of the astronomical literature for the year 1953, amounting to 13,426 papers altogether. It is a most valuable publication, and is prepared at the Astronomischen Rechen-Institut in Heidelberg.

Lines of the Chemical Elements in Astronomical Spectra by Paul W. Merrill. Pages vii plus 167; 8½ × 11 in. Washington, Carnegie Institution of Washington Publication 610, 1956. Price $1.60 (paper), $2.00 (cloth).

The purpose of this monograph is to give a short summary and partial bibliography of lines occurring in astronomical spectra. The arrangement is according to chemical element. The stress is on the occurrence and behaviour of these lines. Appendices include Grotrian diagrams of most elements and ions of astronomical importance from hydrogen to nickel, and a short glossary of special astronomical terms.

Der Sternenhimmel, 1956, edited by Robert A. Naef. Pages 126; 5¾ × 8¼ in. Aarau, Switzerland, H. R. Saurerlander and Co. Price 6.95 Swiss francs.

This year-book, published under the auspices of the Swiss Astronomical Society, has been increased in size by some 20 pages. It may be ordered from Mr. Albert J. Phiebig, P.O. Box 352, White Plains, N.Y.

Mixed Commission on the Ionosphere, Brussels, August 1954, International Council of Scientific Unions. Pages 238; 6¼ × 9½ in. Bruxelles, Secrétariat Général de l'U.R.S.I., 1955. Price $6.00 (U.S.).

This pamphlet reports the proceedings of the fourth meeting held in Brussels from August 16 to 18, 1954. Copies are available from the Secretary General of U.R.S.I., 42 rue des Minimes, Brussels, Belgium.

International Scientific Radio Union, vol. X, parts 3 and 5. Pages 194 and 114; 6¼ × 9½ in. Brussels, Secretary General of U.R.S.I., 1954. Price $4.00, $2.50 (U.S.) respectively.

These pamphlets report on the XIth General Assembly of U.R.S.I. held in The Hague from August 23 to September 2, 1954. Part 3 is concerned with atmospheric radio, part 5 with radio astronomy.

NOTES FROM OBSERVATORIES

David Dunlap Observatory

The Observatory, in co-operation with the University's Department of Electrical Engineering, has begun a programme of radio astronomy research. A grant has been received from the National Research Council for the purpose of building and operating a radio telescope which will be located on the Observatory property. The project is supervised by Dr. Donald A. MacRae of the Observatory Staff and Dr. George Sinclair of the Department of Electrical Engineering. Among the research problems planned for the radio telescope are a study of solar radiation

at moderately low frequency during the forthcoming International Geophysical Year and the measurement of the intensity of radiation from radio stars at a number of frequencies.

During the past year, considerable progress has been made in the application of methods of electronic computation to astronomical problems, using the computer FERUT. Dr. MacRae has devised methods of solving spectrographic binary orbits and Dr. Wellmann has designed methods applicable to the computation of photometric orbits for eclipsing variables. Dr. MacRae has also computed an extensive table for the reduction of radio observations of the 21-cm. hydrogen line radiation in radio astronomy. This is part of an international co-operative project.

Dr. Helen Hogg's extensive "Second Catalogue of Variable Stars in Globular Clusters" has been issued as an Observatory Publication, vol. 2, no. 2. At press at the present time is the report on "The Radial Velocities, Spectral Classification and Photographic Magnitudes of 1041 Late-type Stars" which will be issued as no. 4 in the same volume.

Dr. C. A. Chant, Director Emeritus, celebrated his 91st birthday on May 31st at Observatory House. He enjoys reasonably good health and is able to work some at his desk and go out for an occasional stroll.

Retiring this June is a member of the Staff who has been at the Observatory since before the opening, Mr. Thomas McKenzie, caretaker. Mr. McKenzie's pride in the condition of the buildings and the grounds has been apparent to all who have visited the Observatory. Mr. McKenzie's successor is Mr. Robert Hannah.

Miss Cecily Mader who has filled the position of Secretary and Librarian since 1954 has resigned to be married. Her position has been filled by Mrs. Margaret Lamb.

Appointed to the staff as Lecturer effective July 1st is Dr. Leonard Searle, who until recently has been working at the Institute for Advanced Study at Princeton. Dr. Searle, a graduate of St. Andrews University, has been in the United States since 1952, completing post-graduate studies at Princeton.

Dr. Heard, Dr. Hogg, Dr. MacRae and Miss Northcott attended the Columbus, Ohio, meeting of the American Astronomical Society in March, presenting several papers from the Observatory.

Receiving degrees from the University in Astronomy during May were Miss Olga Boshko, M.A., and Mr. Donald Morton, B.A. Miss Boshko has returned to her position at the Dominion Observatory, Ottawa, and Mr. Morton is spending the summer as assistant at the Observatory, after which, he will enrol as a graduate student in Astronomy at Princeton.

Summer assistants at the Observatory this season included James Hogg

of Queen's University, Philip Locke of the University of Toronto, Henry Zemel of McGill University and Barry Gunn.

Recent visitors at Observatory have been Dr. Rupert Wildt, Yale University, Dr. J. P. Wild, Commonwealth Scientific and Industrial Research Organization, Australia, and Dr. Dean B. McLaughlin, University of Michigan.

J. F. H.

NOTES AND QUERIES

New Studies of Alpha Herculis

A. J. Deutsch of Mount Wilson and Palomar Observatories has recently made an interesting study of Alpha Herculis. This star is a visual double, composed of a supergiant of class M5 (apparent magnitude 5.6) and a yellow giant of class G0 (apparent magnitude 5.4). The spectrograph reveals the G0 star as a close binary system in which the fainter companion star is estimated as class A3 (apparent magnitude 7.7). Spectral lines of intermediate intensity, such as those of iron, shift periodically, showing the spectroscopic pair's orbital motion, but this behaviour is not shared by intense lines such as those of calcium which are relatively stationary in both the G0-A3 pair and the M5 supergiant.

Spectroscopic studies have already suggested that red supergiants are surrounded by extensive shells of expanding gas. The diameter of Alpha Herculis has been measured interferometrically and found to be some 500 million miles. This suggests a shell of about 3 A.U. depth surrounding the supergiant. However, Deutsch now shows that this is a gross underestimate. Both the spectrum of the M5 supergiant and the G0-A3 pair show the same stationary lines produced by the shell. Hence the shell must extend at least as far as the spectroscopic binary—a distance of almost 5 seconds of arc! At a distance from the sun of 150 parsecs, this is equivalent to 700 A.U. This estimate is probably conservative since there is no reason to suppose that the shell ends abruptly at the spectroscopic binary.

B. R. G.

Red Shift of Distant Galaxies Detected at Radio Frequencies

For the first time, the red shift of a galaxy has been detected in the microwave region. Normally the 21-cm. emission line of hydrogen is too

weak in distant galaxies to be observed by existing radio telescopes. A. E. Lilley and E. F. McClain of the Naval Research Laboratory in Washington, D.C., have recently studied successfully the 21-cm. line in the microwave spectrum of Cygnus A, an intense radio source known to be a pair of colliding galaxies. In the case of Cygnus A, if there is neutral hydrogen on the near side of the collision region, then the intense radio radiation would pass through it before reaching intergalactic space. Since these galaxies have a high speed of recession—16,830 km./sec. according to Baade and Minkowski—the 21-cm. line should be shifted by an amount equivalent to a change in frequency of about 81 megacycles/sec. From their measurements Lilley and McClain estimated a velocity of recession of about 16,700 km./sec., a result in excellent agreement with the optical determination. This agreement is evidence that over a large range of frequencies, the red-shift displacement of spectrum lines in distant galaxies is proportional to wave-length, a result of importance in cosmology.

B. R. G.

Period of Rotation of Pluto

Because Pluto is small and is the most distant planet from the sun (more than 3600 million miles) it appears like a star in even the biggest telescopes. It is therefore impossible to determine the period of rotation by directly observing any markings on the surface. However, Merle F. Walker and Robert Hardie, using the 42-inch reflector of the Lowell Observatory, found that the brightness of Pluto changes periodically (*Science News Letter*, vol. 69, no. 4, 1956). This they interpret as being caused by markings on the surface changing the apparent magnitude as it rotates. The variation in brightness is only a tenth of a magnitude. The period of rotation which Walker and Hardie found is 6.390 days. This was determined by combining their recent observations with earlier photoelectric observations by Walker at Mount Wilson and Palomar Observatories and by Kuiper at Yerkes Observatory.

R. J. N.

Double Star Conference

A conference sponsored by the National Science Foundation will be held from August 16–18 inclusive at the Dominion Astrophysical Observatory, Victoria, B.C. Approximately fifteen astronomers have been invited to attend to discuss photometric, astrometric and spectrographic problems arising in the study of double stars, and the methods of promoting double star astronomy generally.

R. M. Petrie

MEETINGS OF THE SOCIETY

AT TORONTO

February 22, 1955—The meeting was held in the McLennan Physics Laboratory. The President, Mr. L. H. Clark, was in the chair.

Dr. J. F. Heard introduced the speaker of the evening, Dr. M. A. Preston, Associate Professor of Physics at Hamilton College, McMaster University, Hamilton. Dr. Preston's topic was, "The Origin Of The Universe". The speaker briefly discussed the history of cosmogony.

Any successful theory of the origin of the universe must explain ages, mass, dimensions and proportions of the various elements present. The major portion of the lecture was devoted to an outline of Gamow's "Explosion Hypothesis" and the Hoyle-Bondi-Gold "Steady-State Theory", giving some indication of their success or failure in meeting the before-mentioned requirements.

Gamow postulates a primordial neutron cloud exploding at time zero. One second after this zero the temperature of the neutron cloud is given as 15 billion degrees with a density of 10,000 gms./c.c. All the elements are formed in the first hour of creation. Gamow's theory succeeds in predicting the age, size of galaxies and distribution of the elements reasonably well. The universe is expanding with a decreasing density. The law of conservation of energy holds true.

The "Steady-State" theory postulates an isotropic universe in time and space, a universe with no beginning or end. In order to overcome the problem of density change caused by expansion of the galaxies the assumption is made that matter is being created at the rate of one neutron per gallon of space every 250 million years. This continuous creation of matter provides new material for galaxies thus maintaining the density. The law of conservation of energy, is abandoned. The theory does not explain too successfully the observed distribution of the elements nor does it explain how neutrons appear in the universe with the required energy and speeds.

In closing, Dr. Preston explained that the expansion of the universe may be cyclic, an expansion followed by a contraction. A coalescing of the material in the universe would destroy the atoms reducing the universe to an undifferentiated gas cloud therefore making it impossible to know if any previous expansion had taken place.

Dr. H. L. Welsh, expressed the thanks of the centre to Dr. Preston for his interesting and informative talk.

March 22, 1955—The meeting was held in the McLennan Physics Laboratory. The President, Mr. L. H. Clark, was in the chair.

Dr. J. F. Heard introduced the speaker of the evening, Miss Ruth J. Northcott, M.A., Assistant Professor of Astronomy at the University of Toronto. Professor Northcott's topic was "The Message of Light". It is essential that a telescope be well constructed so as to hold all optical elements and attached instruments rigidly in place. The mounting should be such as to allow the telescope to accurately follow a star directing the received light on the spectrograph slit throughout long exposures. The speaker explained how the 74-inch reflector at Richmond Hill met these requirements. A general review of the history of spectroscopy led to an explanation of continuous,

absorption and emission spectra, their measurement and calibration with laboratory sources.

The shift of spectral lines either to the violet or red end of the spectrum indicates velocity of approach or recession of the light source (Doppler effect). This effect is utilized to measure radial velocities of stars and the orbital motions of spectroscopic binaries. Measures of spectra provide the information used in establishing the orbital elements of a binary system. Such corrections as spectrograph temperature to standard temperature, allowance for velocity of the earth in different parts of its orbit and observational errors must be made. The data is then reduced by least squares solutions to their most probable values. FERUT is now being trained to perform these tedious calculations.

The David Dunlap Observatory has measured about 1800 radial velocities and contributed almost 12 per cent. of the data published in the Carnegie *Catalogue of Radial Velocities.*

Mr. J. B. Wallace thanked the speaker.

April 5, 1955—The meeting was held in the McLennan Physics Laboratory. The President, Mr. L. H. Clark, was in the chair.

Mr. Clark introduced the speaker of the evening, Mr. D. J. Gerrie, B.A.Sc., whose topic was "Gravitation and Centripetal Force". Mr. Gerrie determined g, acceleration due to gravity, by dropping a weight from various heights which sent an electrical impulse to a timer thus supplying distance and time of fall data.

During the 18th century, Cavendish found the constant of gravitation by means of laboratory experiments. Once this was known the mass and density of the earth, moon and the sun were soon found.

Centripetal force is the force required to restrain an object in motion to a curved path. It acts in a direction normal to the direction of motion and towards the centre of curvature of the path. Centrifugal force is equal in magnitude and direction to the centripetal force, but opposite in sense. The centripetal force (equal to the gravitational force) of the earth about the sun may be found from the fact that during each second, the earth is drawn 0.296 cm. from the orbit's tangent, to maintain a curved path.

In the case of a planet revolving about the sun, potential energy plus kinetic energy equals a constant. This total energy depends on the major axis of the ellipse and not on its eccentricity. If a planet travels in a circular orbit, its velocity is obviously such that the gravitational pull of the sun equals the centrifugal force of the planet.

This velocity is called the "circular velocity", it does not depend on the mass of the planet, but only on the distance (R) from the sun, it decreases as R increases. Since the value of R determines the velocity of a planet, and therefore the period, Kepler's third law may be easily shown to be true.

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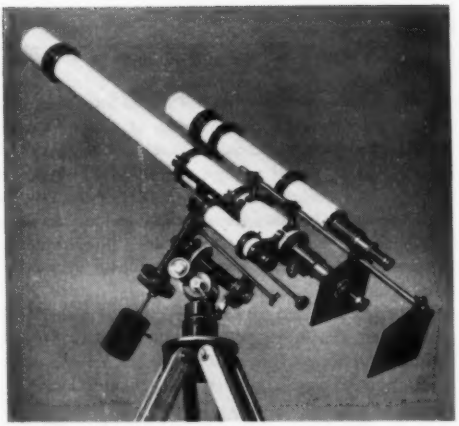

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VOL. L, NO. 4 JULY–AUGUST, 1956 WHOLE NO. 421

PAGE

Canadian Scientists Report

I. The Growth of Astronomy in Canada ..... *R. M. Petrie* 145

Articles

A Stone Pillar on the True Meridian Line ..... *J. E. Kennedy* 152
The Formation of the Planets, Part III (*concluded*) ..... *Gerard P. Kuiper* 158

Variable Star Notes ..... *Margaret W. Mayall* 177

Meteor News

Photographic Meteor Spectra (Appendix 4) ..... *Peter M. Millman* 181

Review of Publications

Principes Fondamentaux de Classification Stellaire edited by M. Schatzman (*J.B.O.*); Studies of Long Period Variables by Leon Campbell, prepared for publication by Margaret W. Mayall (*R.J.N.*); Astronomischer Jahresbericht, vol. 53 edited by Walter F. Wislicenus; Lines of the Chemical Elements in Astronomical Spectra by Paul W. Merrill; Der Sternenhimmel, 1956, edited by Robert A. Naef; Mixed Commission on the Ionosphere, International Council of Scientific Unions; International Scientific Radio Union, vol. X, parts 3 and 5 184

Notes from Observatories

David Dunlap Observatory (*J.F.H.*) 186

Notes and Queries

New Studies of Nova Herculis; Red Shift of Distant Galaxies Detected at Radio Frequencies (*B.R.G.*); Period of Rotation of Pluto (*R.J.N.*); Double Star Conference (*R. M. Petrie*) 188

Meetings of the Society

At Toronto 190

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